# PATENT SPECIFICATION

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## (54) SUPERCONDUCTIVE SWITCHING MEANS

(71) We, COMPAGNIE GENERALE D'ELECTRICITE, a French body Corporate, of 54 rue la Boétie, Paris 8è, France, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to superconductive switching means.

A phenomenon known as "sticking" may take place when a superconductive switching means, passing from its superconductive state into a normal state due to a tripping action, tends to remain in the latter state, despite the cessation of the tripping action.

It has been proposed to connect a superconductive switching means across the terminals of a superconductive storage coil. Whilst the latter remains in the permanent superconductive state, the switching means is required first of all to be in the normal state during the charging phase of the storage coil, and then to be in a superconductive state during the storage phase, and finally in a normal state during the discharging phase. The resistance in the normal state must be sufficiently high relative to a load resistor into which is fed the magnetic energy stored in the storage coil.

Passage from one state to the other may be achieved either by supplying heat energy or by exceeding a critical tripping current or, finally, by magnetic tripping. The temperature, the current and the magnetic field constitute, theoretically, the three parameters permitting passage from the superconductive state to the normal state or *vice versa*. However, thermal diffusion is too slow to trip a high-speed switching means and it is difficult to maintain the current at a constant value if the switching means passes from a superconductive state of zero resistance to a normal state exhibiting extremely high resistance.

Of the three possible means, the magnetic field may be regarded as the most satisfactory for the stated purpose. The magnetic field is obtained with the aid of a secondary winding surrounding the main winding of the switching means, through which secondary winding there travels a current pulse during a predetermined period of time. In the majority of cases, when the pulse duration has elapsed, the superconductive material which has become "normal" remains in the normal state and this is the phenomenon known as sticking.

It is an aim of the present invention to obviate or at least mitigate this disadvantage.

According to the invention there is provided a superconductive switching means comprising a main superconductive winding which is provided with a trip coil and which, in use, is in either a normal state or a superconductive state in dependence on the influence of said trip coil, there being a trip circuit which is connected to said trip coil and is arranged to supply an electrc pulse thereto to cause the main winding to pass from the superconductive state to the normal state and which includes first means for regulating the amplitude of the electric pulse and second means for regulating the duration of said electric pulse, whereby to provide the spontaneous return of said switching means to its superconductive state at the end of the said pulse.

For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawing, in which:—

Figure 1 shows diagrammatically a superconductive circuit including a superconductive storage coil provided with one form of superconductive switching means in accordance with the invention, and

Figure 2 is a diagram illustrating two functioning domains of the switching means.

Referring to Figure 1, the switching means (designated 2) is connected across the terminals of a superconductive storage coil 1 and the switching means 2 and coil 1 together constitute an energy storage loop. The switching means 2 comprises a main winding (not shown) surrounded by a trip winding 7 and the main winding, in use, is in either a normal state or a superconductive state in dependence on the

influence of the trip winding 7. The trip winding 7 receives pulses from a trip circuit which is so adapted as to permit adjustment to the duration and amplitude of these pulses and which comprises a battery of capacitors 8, 9 and a circuit breaker 10. To provide the pulses supplied to the winding 7 the battery of capacitors which have previously been charged are discharged by means of the circuit breaker 10.

The assembly comprising the storage coil 1 and the switching means 2 is disposed in a cryogenic container 3 maintained at the temperature of liquid helium. Charging of the storage coil 1 is effected by a source 4 provided with a circuit breaker 5. A resistor 6 represents the equivalent resistance of a load circuit (connected across the terminals of the coil 1) on discharge of the magnetic energy stored in the storage coil 1. When the storage coil 1 has been charged by the source 4 the circuit breaker 5 is opened and the switching means 2 is closed. The magnetic energy is then stored in the loop comprising the storage coil 1 and the switching means 2. When it is desired to discharge the stored energy into the load resistor 6, the switching means 2 is opened and the energy flows into the said resistor 6. By closing the switching means 2 sufficiently early, it becomes possible to retain the residue of the energy stored and in this way to delay the next storage phase. Opening and closure of the switching means 2 are complicated owing to the fact that the switching means 2 is a superconductive switching means.

It is possible, by arranging a greater or lesser number of capacitors, to vary the amplitude of the electric pulse supplied to the trip winding 7. The number of capacitors in operation may be varied by means of a switching means of suitable type. The duration of the electric pulse is regulated by the duration of closure of the circuit breaker 10. The closure time of the circuit breaker 10 may be regulated by means of a timing relay. The electric pulse travels through the trip winding 7 and creates a magnetic field of predetermined duration and intensity. The main winding of the switching means 2, which is in the zero resistance superconductive state (switching means closed) then passes towards the normal state at which there is a high resistance (switching means open). When the action of the magnetic field ceases, it is necessary that the switching means 2 should return to the superconductive state. This effect involving return to the superconductive state is possible only under certain conditions which are explained by the curve of Figure 2.

Figure 2 represents a graph carrying datum marks with reference to which the duration of the pulse Δt is plotted on the ordinate and the magnetic induction B is plotted on the abscissa. The duration Δt is measured in microseconds and the magnetic induction B in Teslas. The curve of the graph divides the first quadrant into two domains I and II.

In domain I, sticking takes place, i.e. the switching means 2 remains in the normal state when the magnetic pulse which has caused it to pass from the superconductive state to the normal state has ceased to exist.

In domain II, the switching means 2 becomes superconductive once again when the magnetic pulse which has caused it to pass from the superconductive state to the normal state has ceased to exist. For example, magnetic pulse durations of 0.3 microsecond and and magnetic inductions higher than 1 Tesla enable the switching means 2 to return to the superconductive state when 0.3 microsecond has elapsed. These parameters may be obtained by adjusting the duration of closure of the circuit breaker 10 and the charging of the capacitors 8 and 9.

It is clear that the graph of Figure 2 is not limitative and that the domain II is extended in proportion to the extent of heat exchange between the main superconductive winding and its refrigerating fluid. When the tripping pulse of the switching means has ceased to exist, the main winding becomes more readily superconductive in proportion to the ease with which the refrigerating fluid is able to evacuate the heat energy excesses.

The main winding of the switching means 2 comprises either thin superconductive layers of fine wires embedded in a resistant matrix. The main winding is designed, in both these cases, as a heat exchanger affording the maximum heat exchange surface with the refrigerating fluid. In the normal state, it is necessary that the switching means should have an extremely high resistance, so as to reduce the passage of the discharge current. In fact, the increase in the discharge current produces a harmful increase in the switching means temperature.

The switching means described above may be employed in all cases wherein it is necessary to bring about the immediate return thereof to the superconductive state after being in the normal state. It may be employed particularly for delaying the next storage phase and permitting further discharge of the storage coil without it being necessary to recharge it beforehand.

Particularly interesting applications may be found in the field of plasma discharges or laser flash tubes.

WHAT WE CLAIM IS:—

1. Superconductive switching means comprising a main superconductive winding which is provided with a trip coil and which, in use, is in either a normal state or a superconductive state in dependence on the influence of said trip coil, there being a trip circuit which is connected to said trip coil and is arranged to supply an electrical pulse thereto to cause the

main winding to pass from the superconductive state to the normal state and which includes first means for regulating the amplitude of the electric pulse and second means for regulating the duration of said electric pulse, whereby to provide the spontaneous return of said switching means to its superconductive state at the end of the said pulse.

2. Switching means according to claim 1, wherein said second means is so adjusted that the duration of the electric pulse is shorter than 0.3 microsecond and said first means is so adjusted that the electric pulse has the required amplitude to provide in said trip coil a magnetic induction higher than 0.1 Tesla.

3. Switching means according to claim 1 or 2, wherein said first means comprises a battery of capacitors.

4. Superconductive switching means according to any preceding claim, wherein said second means comprises a circuit breaker provided with a timing relay.

5. Superconductive switching means substantially as hereinbefore described with reference to the accompanying drawing.

6. A superconductive circuit comprising a superconductive storage coil, superconductive switching means according to any preceding claim and connected across said storage coil so that said storage coil and said switching means together provide an energy storage loop, a power source connected to said switching means whereby to supply power to said storage coil to store energy in said loop, and a load connected across said storage coil so as to receive the energy stored in said loop on switching said switching means to its normal state following a period of storing energy in said loop.

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1351969 COMPLETE SPECIFICATION

1 SHEET This drawing is a reproduction of the Original on a reduced scale

FIG. 1

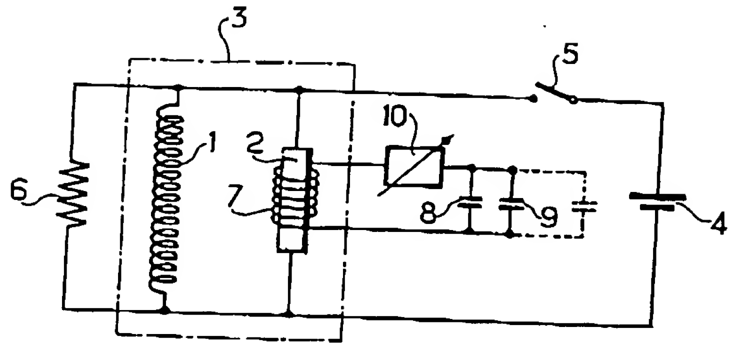


FIG. 2